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THE PULSE REACTOR POTENTIALITIES
(For Neutrino Investigations.I)

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I. Introduction

The purpose of this report is to attract attention on possible use of pulse reactors for neutrino investigation in the presence of high cosmic and natural radiation background. The neutrino (and antineutrino) interaction cross-sections for nucleons and especially for electons are generally known to be very small. For this reason the registration of neutrinoes from a power reactor must be done under background many times as much as the effect. A pulse reactor gives much more better conditions for the experiments which demand a great neutrino generating rate in the pulse. Therefore, such a reactor differs from usual research reactors with a high neutron density (1). The practice of USSR uranium-graphite pulse reactor IGR (2) gives the opportunity to design pulse reactor with power of some 10^9kW, the pulse duration being about 1 second. The evaluation shows that it is sufficient for measuring the antineutrino-electron scattering cross-section.

A number of versions of the reactor as antineutrino generator were considered, all giving approximately equal opportunities for antineutrino generation. It was supposed the core to be consisted of the graphite sections saturated with uranium as in IGR. The new characteristics of the reactor are the greater dimensions and the arrangement of heat-transfer tubes into graphite sections for rising a cooling rate (period of some hours made).

The next relations are useful in analysis of antineutrino generation methods. Let "η" be a number of

counts per one neutron absorbed in a fuel (U-235). For average reactor power "Q_{av}" and duration of experiment "t" we have number of counts

$$N_3 = \eta \frac{Q_{av}}{E} t$$

Here "E" - extracted energy for neutron absorbed by uranium nucleons.

Background counts for the same time is proportionate to an effective interval of neutrino generation in reactor pulses:

$$t_e = \frac{t}{\tau / \Delta t_e}$$

where τ is the interval between pulses
and Δt_e is the effective interval of antineutrino generation, proportionate to the measurement duration.

Approximately $\Delta t_e \sim \lambda^{-1}$, where λ decay probability of activated nuclei emitting the antineutrino. If the background is not due to a reactor operation and gives a counting rate „n" , statistical uncertainty of the measurement will be of order

$$\frac{\sqrt{n t_e}}{N} = \frac{E \sqrt{n}}{Q_{av} \eta \sqrt{\tau \lambda t}}$$

(It was supposed that $n t_e \gg N$). For stationary reactor operation with the same value Q_{av} the uncertainty will be as much as $\sqrt{\tau \lambda}$ times greater.

Costs of construction and reactor exploitation is defined roughly by dimensions and average power. It is profitable to diminish an average power Q_{av} and to increase τ, keeping the accuracy of the measurements. However, there is a relationship for the pulse reactor: $Q_{av} = \frac{J}{\tau}$ where J is the energy accumulatible by reactor. For this reason the accuracy of the measurements is defined by value $\eta Q_{av} \sqrt{\tau} = \eta \sqrt{Q_{av} J}$. Diminishing of Q_{av} demands an increase of J , that is an increase of reactor dimensions and is profitable limitedly.

The necessary antineutrino flux was evaluated by Spivak and Mikaelyan and their results allowed to estimate the reactor dimensions and pulse period. They also proposed
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the idea of usage Li^7 to generate the antineutrinoes of high energy in the reactor.

2. Usage of Fragment Antineutrinoes

For measurement of an antineutrino-electron scatterring cross-section the integral antineutrino flux from fission fragments, produced in reactor pulse, must be

$$f = 1{,}7 \cdot 10^{17}\,cm^{-2}\,\sqrt{\tau}\,(day)^{-1}$$

each fragment presuming to be source of one antineutrino. Pulse duration must be less than 10 seconds. An experimental installation (detector system) has to be placed into the reactor to increase a counting rate. The spherical layer reactor with radii 7.25 m and 9.85 m (core thickness 2.6 m) and with shielding thickness 4 m has an inside volume 145m^3. A core volume is 7000 m^3 and the weight 10^4 tons (passage to the lab taken into account). This weight is as much as 2500 times greater than one for IGR. A power pulse will make about 2.5×10^{13} joules of heat. Corresponding number of antineutrinoes is 1.55×10^{24} and integral flux is

$$f \approx 1{,}7 \cdot 10^{17}\,cm^{-2}$$

in the lab. It is sufficient to repeat the pulse once per day, the average reactor power being $Q_{av} = 300000$ kW. The reactor is cooled after the pulse immediately much more intensively than at average and the power of cooling system is to be about 10^6 kW.

The fuel burning up is $\Delta G_5 = 100$ kg of uranium for the continuous operative year, with operative charge $G_5 = 2000$ kg. More cheap semisphere version of the reactor with the same antineutrino efficiency has the next characteristics:

$G_c = 5000$ t, $G_5 = 1000$ kg

$\mathcal{J} = 1250$ joules, $\tau = 6$ h, $Q_{av} = 600000$ kW.

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3. Li^7 Activation

The activation of Li^7 in reactor may be used to obtain the high energy antineutrinoes [3]. The measurable antineutrino flux in a pulse is $f = 4.5 \cdot 10^{15} cm^{-2} \sqrt{\tau (days)}^{-1}$ (beyond shielding). The life-time of a Li^8 nucleus is $\lambda^{-1} = 0.85$ sec. There is possibility to take out the activated lithium as antineutrino source from reactor into collector with effective distance to detector about 3.5 m. The collector has to accumulate $7.10^{21} \sqrt{\tau (days)}^{1}$ of Li^8 nuclei per pulse. The estimation of pulse reactor dimensions may be easely made supposing the pulse duration as well as time of lithium transfer to a collector is one second, a succession pulse interval is $\tau = 2.5$ hours. Li^7 has to capture 5.10^{21} neutrons, radioactive decay being taken into account. Li^7 must be of a high purity (the relative Li^6 concentration is of order 3.10^{-5}), so half of absorbed neutrons by lithium produce activated Li^7. The uranium absorbs neutrons twice as much as lithium (for given uranium-to-lithium ratio), that is 2.10^{22} neutrons per pulse. It means $J = 54 x 10^{10}$ joules extracted. Reactor construction requires about 200 tons of graphite if heating non-uniformity is similar to that of IGR. For operative year the fuel burn-up results 7.10^{25} U-235 nuclei, i.e. G_5 - 30 kg. The neutron absorbing in lithium comparatively with that in U-235 is 25% at average for operative period, at the end of it $K_s \simeq 1$, taking into account the fragment accumulation and burning-up of Li^6. The reactor must have an outside layer of the core with $K_s > 1$. At the end of operative period $K_s \simeq 1,3$ providing the lithium removal. The volume of the core layer which keeps the reactor at power is 1.5 times as much as one of core with $K_s = 1$. The full uranium charge is G - 200 kg and pulse heat $J = 125.10^{10}$ joules respectively. There is no need to provide the criticality of hot reactor in the regime of self-

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quenching pulse, and dimensions of periphery layer with $K_5 \simeq 1,3$ decrease. In this case $G_5 = 175$ kg and $J = 110.10^{10}$ joules. A pulse duration is less than one second, a mean reactor power - Q_{av} 125000 kW. A capacity of heat extraction system must be some times as much as this (about 0.5×10^6 kW).

4. Comparison of Different Variants of Reactor

The comparison of variants with and without lithium shows that the use of 10 tons of high purity Li^7 gives the opportunity to decrease the average power - 10 times, graphite, saturated with uranium - 10 times, uranium charge -5 times. In lithium variant there is no need to uniform the neutron distribution. However, the average heat extraction in the core with lithium has to be decreased approximately 2.5 times, the same rate increasing the quantity of lithium; the uranium and graphite loading is not changed.

The distance from the experimental installation to the centre of reactor is considerably greater than to the lithium collector. Therefore, the replacing of lithium to the collector permits to diminish the quantity of pulse produced Li^8 2.5 times. That means a decrease of graphite, uranium and average power 2.1 times. But the gain makes the reactor construction more complicated.

The further complication gives the additional decreasing of lithium, if to use the moving wave (regime of cycle-pile) (4) instead of self-quenching pulse. The core, free of lithium, and the lithium screen have to run around the reactor body for one second, with the speed about 20 m/sec.

Table I shows the variants discussed. They are comparable concerning the possibility of antineutrinoes experiments, but differ by the technique complication. Variant 1 is the most simple and bulky (without Li^7). Variant 2 demands much Li^7 of high purity and a solution of a new technologi-

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cal problem: to construct lithium sections stable at the conditions of high temperature and radiation. The jacket materials of these sections must be bad absorbers of neutrons and gamma-rays (gamma-rays absorption leads to the overheating). However, the dimensions and cooling capacity of variant 2 are considerably decreased. The variant 3 gives more of latter gain, but much more complicated: the high speed transfer of irradiated lithium and the construction of transporting system in the reactor.

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Table I

Comparison of Reactors as Antineutrino Generators

N°	G_C x) t	G_5 kg	G_{Li} xx) t	J joule	τ hour	Q_{av} 10^3kW	f 10^{15}cm^{-2}	N o t e
1	5000	1000	0	1250	6	600	85	Fragment (soft) antineutrinoes
2	1000	400	25	230	2.5	260	1.5	Antineutrinoes of high energy. Lithium immovable
3	500	175	10	110	2.5	125	1.5	Antineutrinoes of high energy. Lithium speed 10 m/sec.

x) Without graphite reflector

xx) Admixture of Li^6 in Li^7 is $3x10^{-5}$

Literature

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Annotation

Pulse reactor is profitable for physical investigation when the effect-to-background ratio is not small. Variants of a pulse reactor for the antineutrino experiments are discussed. The reactor with pulse heat extraction 1.25×10^{13} joules and with average power of 600000 kW gives the fragment antineutrino flux, sufficient for measurement the antineutrino-electron scattering cross section. The reactor has a graphite core with 1000 kg U-235. The antineutrinoes of high energy may be produced by Li^7, activated in the reactor. It leads to the dimension and power decrease: pulse heat extraction - 5 times, average power - 2 times, uranium charge - 5 times. Lithium of high purity is required 25 tons. The further dimension and power decrease is due to the complicated construction: pulse irradiated lithium is fransferred to the special collector.The decrease rate comparatively with the previous variant: pulse heat extraction - 2 times, average power - 2.4 times, lithium - 2.5 times. The variants are suitable for the antineutrino experiments.

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